Satellite Ocean Color/Biogeochemistry Climate Data Records

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Ocean Biology Processing Group

NASA MODIS Science Team Meeting

March 22-24, 2005
Seasonal Biosphere
Ocean Chlorophyll-a & Terrestrial NDVI

Data from SeaWiFS
Carbon Cycle and Ecosystems Roadmap

**Goals:** Global productivity and land cover change at fine resolution; biomass and carbon fluxes quantified; useful ecological forecasts and improved climate change projections

**Knowledge Base**

- Human-Ecosystems-Climate Interactions (Model-Data Fusion, Assimilation); Air-Sea Flux
- Southern Ocean Carbon Program, Air-Sea CO₂ Flux
- Vegetation 3-D Structure, Biomass, & Disturbance
- Coastal Carbon
- Global Ocean Carbon / Particle Abundance
- Reduced flux uncertainties; coastal carbon dynamics
- N. America's carbon budget quantified
- Regional carbon sources/sinks quantified for planet
- Effects of tropical deforestation quantified; uncertainties in tropical carbon source reduced
- Models w/improved ecosystem functions
- Human-Ecosystems-Climate Interactions (Model-Data Fusion, Assimilation); Air-Sea Flux
- High-Resolution Atmospheric CO₂ (OCO)
- CH₄ sources characterized and quantified
- Systematic Observations: Process controls; errors in sink reduced

**Report**

- Vegetation (AVHRR, MODIS)
- Ocean Color (SeaWiFS, MODIS)
- Land Cover (Landsat)
- Land Use Change in Amazonia
- N. American Carbon Program
- Southern Ocean Carbon Program, Air-Sea CO₂ Flux

**2002:** Global productivity and land cover resolution coarse; Large uncertainties in biomass, fluxes, disturbance, and coastal events

**2004:** Funded

**2006:** Unfunded

**2008:** Partnership

**2010:** T = Technology development

**2012:** = Field Campaign

**2014:** Report

**2015:** Integration of global analyses

**Systematic Observations**

- Bridge (LDCM)
- Land Cover (OLI)

**2002:** Global CH₄; Wetlands, Flooding & Permafrost

**2004:** Global Atmospheric CO₂ (OCO)

**2006:** N. American Carbon Program

**2008:** Land Use Change in Amazonia

**2010:** Global CH₄; Wetlands, Flooding & Permafrost

**2012:** Southern Ocean Carbon Program, Air-Sea CO₂ Flux

**2014:** Global C Cycle

**2015:** Global C Cycle
Data Requirements for Climate Research: Climate Data Records

- **Long-term continuous time series**
  - Must span interannual and short-term natural variability (e.g., ENSO)
  - Necessarily requires data from multiple missions (e.g., CZCS to NPOESS)
  - Must include most recent data, e.g., NPP/VIIRS
    - Continuous ocean color time series starts in 1996 with ADEOS-I/OCTS
  - Must minimize data gaps to avoid aliasing of natural climate oscillations (e.g., ENSO)

- **Highest possible quality (satellite & in situ)**
  - Must not include significant sensor artifacts and trends
    - Decadal scale variability and climate trends are small and can be easily confused with sensor drift
    - Ocean color products are particularly sensitive to sensor characterization/calibration errors (e.g., 1% error in calibration produces about a 10% error in water-leaving radiance)
  - Must be validated with ample highly accurate field data
  - Requires reprocessings (e.g., SeaWiFS has been reprocessed 5 times in 7.5 years)

- **Consistency between satellite data sets**
  - Must be cross-calibrated and processed using similar algorithms, i.e., no abrupt transitions between data sets
  - Requires periodic reprocessings to improve products & maintain consistency
## Global Ocean Biogeochemistry Missions

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**Note:** CZCS (1978-1986) did not routinely collect global data.

*MODIS/Terra ocean color data not presently in production

**NPP launch will probably slip
Historical Ocean Color Accuracy Goals

- **Sensor radiometric calibration**
  - ±5% absolute
  - ±1% band-to-band relative

- **Water-leaving radiances**
  - ±5% absolute

- **Chlorophyll-a**
  - ±35% over range of 0.05-50.0 mg/m³

These accuracy specifications are being reconsidered based on experience with SeaWiFS & MODIS.
Infrastructure Requirements for CDR Development

- Protocols for laboratory & in situ observations
- Advanced instrumentation development & ongoing instrument performance evaluations
- Calibration and data analyses round robins
- In situ data archive and standardized QC procedures
- Algorithm development (atmospheric & bio-optical)
- On-orbit calibration capabilities
  - On-board methods (e.g., lunar data)
  - Vicarious methods (e.g., MOBY)
- Multi-mission reprocessing capability
Main Processing System

- Data from multiple satellite and instrument types
- In-situ, ancillary, and other data

Science Community Interactive
- Knowledgeable Staff
- Enabling Activities (SeaBASS, SeaDAS, Calibration RR, etc.)

Flexible Processing
- Multiple Missions
- Rapid Reprocessing
- Parallel Processing Streams (operational, algorithm & calibration testing, evaluation products)

Reconfigurable & Scalable

CZCS & OCTS

SeaWiFS

Terra MODIS

Aqua MODIS

NPP VIIRS

GSFC DAAC

L1 DATA

L1-L3 DATA

Data Users

MCST

NASA HQ Program Management

NASA Flight Projects

Science Community

In Situ Data

Community Agreed Standards and Protocols

Historical (REASON-CAN)

Present (EOS, other)

Future (NPP)

Ocean Biology Processing System

Data Set Category: Funding Source

OBPG Management & Staff

Ocean Biology Processing System

Funding Source

* MODIS Characterization Support Team (NASA/GSFC)

# Terra MODIS OC processing suspended in Jan. 2004
Calibration Validation Paradigm

Satellite Calibration Elements:

- **Laboratory** - before launch, sensor is calibrated in lab
- **On-orbit** - daily solar and monthly lunar observations are used to track changes in sensor response
- **Vicarious** - comparison of data retrievals to in-water, ship, and airborne sensors is used to adjust instrument gains
Ocean Optics Protocols for Satellite Ocean Color Sensor Validation

Original Protocols:

Revisions and Other Protocols:
MOBY used to adjust prelaunch calibration gains for visible bands using satellite-buoy comparisons.
Data from over 1360 cruises
Apparent Optical Property (AOP); Chlorophyll-a (CHL); Aerosol Optical Thickness (AOT)
SeaWiFS & SIM BIOS Calibration Round Robins


Goals

- Verify that all labs are on the same radiometric scale
- Document calibration protocols
- Encourage the use of standardized calibration protocols
- Identify where the protocols need to be improved
Field Measurement Technology Development

Various in-water & above water radiometers

SeaWiFS Quality Monitor (SQM)
(NIST/NASA-developed portable field source for stability monitoring)
SeaWiFS, MODIS, & VIIRS

- **SeaWiFS**
  - Rotating telescope
  - 412, 443, 490, 510, 555, 670, 765, 865 nm bands
  - 12 bit digitization truncated to 10 bits on spacecraft
  - 4 focal planes, 4 detectors/band, 4 gain settings, bilinear gain configuration
  - Polarization scrambler: sensitivity at 0.25% level
  - Solar diffuser (daily observations)
  - Monthly lunar views at 7° phase angle via pitch maneuvers

- **NPP/VIIRS**
  - SeaWiFS-like rotating telescope
  - MODIS-like focal plane arrays
  - No polarization scrambler
  - Solar diffuser with stability monitor
  - 7 OC bands (412, 445, 488, 555, 672, 746, 865 nm)

- **MODIS (Ocean Color)**
  - Rotating mirror
  - 413, 443, 488, 531, 551, 667, 678, 748, 870 nm bands
  - 12 bit digitization
  - 2 Vis-NIR focal planes, 10x40 detector arrays
  - No polarization scrambler: sensitivity at ~3% level
  - Spectral Radiometric Calibration Assembly (SRCA)
  - Solar diffuser (observations every orbit), Solar Diffuser Stability Monitor (SDSM)
  - Monthly lunar views at 55° phase angle via space view port
SeaWiFS Calibration Strategy

  - Complete sensor calibration and characterization by Santa Barbara Research Center prior to delivery of sensor to OSC

- Pre-launch Calibration Recertification (1997)
  - Recalibration by NIST at OSC just before launch

- Independent on-orbit calibration test after operations began in 1997

- SeaWiFS Launch

- Solar Calibration for a Transfer-to-Orbit Comparison

- Onboard Calibrations (time dependency corrections)
  - Lunar Calibrations (monthly)
  - Solar Calibrations (daily)

- Vicarious Calibration and Product Validation
  - MOBY Calibrations (bands 1-6)

- Time-series Evaluations
  - In Situ Bio-optical and Atmospheric Data Comparisons

- Global 8-day Clear Water Analysis

Community-wide activities to ensure consistent data from various sources
Lunar calibration: Monthly views of the moon at ~ 7° phase angle. Gradual monotonic degradation primarily in NIR bands.
MOBY-based Vicarious Band 1 Gain Factors

- Overpasses used in operational gain determination
- Overpasses that failed gain analysis Q/C criteria
SeaWiFS Data Quality: Global Consistency & In Situ Verification

Field Validation: Lwn’s

* Lwn: Normalized Water-leaving Radiance
MODIS/Aqua Data Quality: Global Consistency & In Situ Verification

Field Validation: L wn’s

* L wn: Normalized Water-leaving Radiance

Field Validation: Chl-a

chlorophyll
MODIS(Aqua)/SeaWiFS Lwn Ratios (Hawaii):
Vicarious Calibration Region

- Most MOBY data used for vicarious calibration is near beginning & end of time series due to sun glint
- Differences during 2003 are presently unexplained
MODIS/Aqua-SeaWiFS Global Lwn’s

- Global averages very consistent.
- Average differences within ±5%.

Deep-Water Lwn Comparisons
Solid Line: SeaWiFS
Dashed Line: MODIS/Aqua

Deep-Water Lwn Ratios
MODIS-Aqua/SeaWiFS Meridional Clear-Water Lwn Comparisons (Global Daily Mean)

March, 2003

June, 2003

September, 2003

December, 2003
MODIS-Aqua & SeaWiFS Global Mean Chlorophyll Time Series

Clear-water: chl-a < 0.15 mg/m³

Deep-water: depth > 1000 m

Coastal: depth < 1000 m
- Primarily chlorophyll-a algorithm difference at high concentrations

Dashed line: MODIS
Solid line: SeaWiFS
SeaWiFS & MODIS 4-Day Deep-Water Chlorophyll Images
4 day composites, Summer 2002

SeaWiFS

MODIS (current operational processing)
Global Ocean Color/Biogeochemistry Trends: Recent Case Studies

  - Global marine productivity increased by 6 petagrams C/yr between Sept. 1997-August 2000
  - Global terrestrial productivity showed no significant change, only regional changes
  - Marine productivity declined > 6% over past 2 decades
  - Ocean gyre chlorophyll concentrations decreasing with increasing SST
  - Most oligotrophic areas also expanding: McClain et al., *Deep-Sea Res.*, 2004
Global Patterns of Net Primary Production (NPP) & NPP Anomaly: 1998-2000

Global NPP Trends: 1997-2000

Oceans

Year

Global Monthly Mean NPP (Pg/m²)

1998 1999 2000

4.0 4.5 5.0 5.5

Land

Boreal Winter

Boreal Summer

Monthly Anomaly

Anomaly (g C m² month⁻¹)

Decadal Scale Changes in Marine Productivity

- 70% of change at high latitudes.
- Productivity tended to increase at low latitudes.


Gregg, W.W., et al., GRL, 2005
Temporal Variations in Ocean Central Gyre Chlorophyll-a & SST Mean Values: 1998-2003

Gregg, W.W., et al., GRL, 2005
Maintaining the Ocean Color CDRs: Data Set Reprocessings

- Historical Data Sets (REASoN-CAN, Watson Gregg, PI)
  - OCTS: Reprocessing scheduled for Spring 2005
  - CZCS: Reprocessing scheduled for CY 2005
- SeaWiFS: Reprocessing completed in March 2005 (4 km data @ 3700X)
- MODIS/Aqua: Reprocessing completed in March 2005 (1 km data @ 150X)
BACK-UP SLIDES
**Ocean Color & Carbon Cycle/Ecosystems/Biogeochemistry: NASA Science Objectives**

- **Why do we care about ocean biogeochemistry?**
  - The ocean is a primary sink for anthropogenic CO$_2$.
  - The ocean is the largest active reservoir of carbon.
  - Marine photosynthesis supports the entire marine foodweb (fisheries).

- **Major Ocean Biogeochemistry Science Questions**
  - Ocean biology interannual variability (e.g., El Niño/La Niña)
  - Impacts of climate change/warming on marine ecosystems
  - Marine CO$_2$ sequestration and role of “biological pump”
  - Impacts of population growth on coastal ecosystems

- **Data Requirements**
  - Long time series of global observations (from multiple sensors)
  - Consistent and accurate on-orbit sensor calibrations
  - Improved accuracy in data products (e.g., chlorophyll-a, primary productivity), particularly in coastal regions
  - Adequate field/laboratory calibration & validation program
# Ocean Color Data Processing, Cal/Val, & Algorithm Development Functions

## Algorithm Development & Field Data Collection
- Algorithms
  - Atmospheric correction
  - Quality masks & flags
  - Bio-optical
  - Sea surface temperature
  - Data merger (time/space)
- Bio-optical & atmos. field data collection
- Science leadership/coord
- New product specification
  - Definition/Development
  - Resource/Performance Evaluation
  - Selection

## Sensor Calibration & Product Validation
- I/F with mission operations
  - Cal. strategies, schedules, and operations plans
- Round robins
  - Visible
  - Thermal IR
- Vicarious calibration
  - Data: MOBY, AERONET, ship
  - Data Analysis
- Protocol development for measurement and analysis
- Instrument technology evaluation
- I/F with sensor/satellite mission calibration and characterization activities/groups (e.g., NCST)
- Q/C & archive in-situ data
  - (product validation & algo. dev.)
- Product validation
  - Discipline Processing Group
  - Science Team

## Data Processing
- I/F with IPO & NOAA
- I/F with NPP/CDMS
- Maintenance and infrastructure improvements within GSFC
- Climate data processing
  - Continuity data sets & data merger (historical/existing)
  - VIIRS
    - Simulated data develop.
    - End-to-end testing
- Data storage
  - RDRs, Level-1, EDRs
  - Ocean & ancillary data
- Algorithm testing & implementation (inc. new products)
- Quality control/assurance
  - Continuity data sets
  - VIIRS

## Distribution & Outreach
- Real-time ground station support
- Data archive & distribution
- Community processing S/W (SeaDAS)
- Data Synthesis
- Science campaign support
  - Autonomous support
  - User services
  - Interface and data processing capability
- RT data distribution
- Publication support
  - Science writer/editor
- Education outreach

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Functions supported under NRAs

Discipline processing functions

Functions assumed by a NASA flight project, HQ, or another agency (NOAA)
Ocean Color 865 nm Band: No Vicarious Calibration

- 865 nm measurements are used provide aerosol amounts in the atmospheric correction algorithm
  - SeaWiFS, MODIS, OCTS, VIIRS
- Comparisons for SeaWiFS suggest that band 8 calibration may be 5-10% too high
  - Southern Ocean band 8 gain study (~5-6%)
  - Comparisons with University of Arizona ground measurements (within 10%)
  - Comparisons with aerosol optical thickness data (AERONET & cruise data)
    - Scatter in results is large
    - SeaWiFS appears high
Time Series of Global Ocean Chl-a & Chl-a Anomaly, 1998-2000
